Releases of *Psyttalia fletcheri* (Hymenoptera: Braconidae) and Sterile Flies to Suppress Melon Fly (Diptera: Tephritidae) in Hawaii

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ABSTRACT Ivy gourd, *Coccinia grandis* (L.) Voigt, patches throughout Kailua-Kona, Hawaii Island, HI, were identified as persistent sources of melon fly, *Bactrocera cucurbitae* (Coquillett). These patches had a low incidence of *Psyttalia fletcheri* (Silvestri), its major braconid parasitoid natural enemy in Hawaii, and were used to evaluate augmentative releases of *P. fletcheri* against melon fly. In field cage studies of releases, numbers of melon flies emerging from ivy gourd fruit placed inside treatment cages were reduced up to 21-fold, and numbers of parasitoids were increased 11-fold. In open field releases of *P. fletcheri* into ivy gourd patches, parasitization rates were increased 4.7 times in release plots compared with those in control plots. However, there was no significant reduction in emergence of melon flies from fruit. In subsequent cage tests with sterile melon flies and *P. fletcheri*, combinations of sterile flies and *P. fletcheri* produced the greatest reduction (9-fold) in melon fly emergence from zucchini, *Cucurbita pepo* L. Reductions obtained with sterile flies alone or in combination with parasitoids were significantly greater than those in the control, whereas those for parasitoids alone were not. Although these results suggest that the effects of sterile flies were greater than those for parasitoids, from a multitactic melon fly management strategy, sterile flies would complement the effects of *P. fletcheri*. Cost and sustainability of these nonchemical approaches will be examined further in an ongoing areawide pest management program for melon fly in Hawaii.

KEY WORDS *Bactrocera cucurbitae*, augmentative parasitoid releases, sterile fly releases

Melon fly, *Bactrocera cucurbitae* (Coquillett), is a serious agricultural pest of cucurbits. It has been recorded from >125 plant species (Weems 1964) and is found in India, Myanmar, Malaysia, Thailand, the Philippines, southern China, Taiwan, eastern Africa, Guam, the Commonwealth of the Northern Mariana Islands, New Guinea (Papua), Solomon Islands, Nauru, and the Hawaiian Islands (Nishida 1953, White and Elson-Harris 1992). In 1895, it was discovered in Hawaii (Back and Pemberton 1917), where it causes serious economic damage to cultivated species of Cucurbitaceae [e.g., cucumber, *Cucumis sativus* L.; watermelon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai; cantaloupe, *Cucumis melo* L.; bitter melon *Momordica charantia* L.; pumpkin and zucchini, *Cucurbita pepo* L.]. When populations are high and cucurbits scarce, melon flies also attack, but less frequently, species of Solanaceae (e.g., tomato, *Lycopersicon esculentum* Mill.; eggplant, *Solanum melongena* L.; and bellpepper, *Capsicum annuum* L.), Rutaceae (e.g., citrus, *Citrus* spp.), Myrtaceae (e.g., common guava, *Psidium guajava* L.; and strawberry guava, *Psidium cattleianum* Sabine), Rosaceae [e.g., loquat, *Eriobotrya japonica* (Thunb.) Lindl. and peach, *Prunus persica* (L.) Batsch.], and Passifloraceae (e.g., passionfruit, *Passiflora edulis* Sims) (White and Elson-Harris 1992, Ramadan and Messing 2002). Two major feral hosts are wild bitter melon and ivy gourd, *Coccinia grandis* (L.) Voigt (Liquido et al. 1990, Uchida et al. 1990).

Establishment of melon fly in Hawaii resulted in the introduction of many natural enemies. Nishida (1955) listed a total of eight species of hymenopterous parasitoids and six predators found in Hawaii; however, all of the parasitoids, except *Psyttalia fletcheri* (Silvestri), were of little importance from the standpoint of biological control, primarily because of their scarcity and nonspecificity to melon fly. *P. fletcheri*, a widespread larval-pupal parasitoid of melon fly in India, was introduced into Hawaii in 1916 (Willard 1920, Clausen et al. 1965). The kind of host fruit infested by melon fly seems to influence *P. fletcheri* parasitization rate. For example, Nishida (1955) found little or no parasitization of larvae in papaya, *Carica papaya* L., bellpepper, and tomato. Willard (1920) reported that parasitization of larvae in cucumber fruit ranged from 7.3 to 29.8%, whereas parasitization on wild bitter

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melon fruit was as high as 96.9%. Host larvae location in different parts of the same plant also influenced the parasitization by *P. fletcheri.* For example, in melons, where the larvae may be found in both vines and fruit, consistently higher parasitization was obtained in vines (Nishida 1955). Apparently, in vines, the larvae are situated just beneath the epidermis throughout the developmental period and are within reach of the parasitoid's ovipostior for a longer time. However, larvae during later stages of development have a tendency to burrow deeply into the flesh of the fruit and are less accessible to parasitoids.

Ivy gourd is native to Africa, but it also occurs wild in the Indo-Malayan region (Singh 1990) and is naturalized in parts of Australia, the Carribbean, the southern mainland United States, and several Pacific Islands (Linney 1986, Telford 1990). During the 1960s, it was accidentally introduced into Hawaii, where it is considered a noxious weed and a target for biological control (O'Brien and Pakaluk 1998, Chun 2001). Ivy gourd frequently blankets trees, understory vegetation, fences, and other artificial structures in residential and agricultural areas (Chun 2001). Presently, ivy gourd is restricted in Hawaii to Oahu Island and to the leeward side of Hawaii Island, specifically to the Kailua-Kona area. It is a perennial climbing vine with a tuberous rootstock producing annual stems up to several meters long. Main stems may be 5–8 cm in diameter at ground level, and the plants start new growth rapidly after rainfall. Fruit are green with longitudinal white stripes when immature, but change to scarlet red at maturity. They are 25–60 mm in length and 15–30 mm in diameter (Telford 1990). Seeds are spread by birds, rodents, and humans (Uchida et al. 1990). Both Uchida et al. (1990) and Jackson et al. (2003) found ivy gourd to be a major source of melon flies.

Reported here are studies in Kailua-Kona, HI, on *P. fletcheri* and melon fly ecology in ivy gourd and on effects of augmentative releases of *P. fletcheri.* Furthermore, we examined the potential effects of sterile melon fly and *P. fletcheri* releases on wild melon fly abundance. Specifically we studied (1) annual *P. fletcheri* parasitization of melon fly breeding in ivy gourd patches, (2) field cage releases of *P. fletcheri* against melon fly infesting ivy gourd fruit, (3) open field releases of *P. fletcheri* against melon fly infesting small patches of ivy gourd, and (4) field cage releases of *P. fletcheri* and sterile flies against melon fly infesting zucchini fruit.

Materials and Methods

Melon Fly and *P. fletcheri* Ecology. Ten patches of ivy gourd throughout the Kailua-Kona, HI, area (Fig. 1) were surveyed from April 1996 to March 1997 to determine melon fly abundance. A male melon fly bucket trap, constructed from plastic containers (Highland Plastics, Pasadena, CA) and baited with a mixture of cue-lure and naled (Dibrom Concentrate, Valent USA Corp., Walnut Creek, CA), was maintained in each patch (Vargas et al. 1989, 1990, 2003b). Flies captured in traps were collected and counted monthly. Presence of ripe fruit in patches varied seasonally. Approximately, 100 fruit (three-fourths to fully ripe) were collected randomly from each plot monthly. Fruit were weighed and placed in batches of 100 on a wood-framed metal screen (43 by 28 by 6 cm) inside fiberglass holding boxes (50 by 32 by 15 cm) that contained 1.5 cm of sand. Fruit were held for 3 wk. Boxes were provided with screened ventilation holes on the sides and a pair of plastic drip pans (25 by 19 by 3 cm) between the screen and the sand-lined bottom to collect fruit juice. A fine mesh nylon screen was placed over pans to prevent larvae from falling into juice. Sand from fruit holding boxes was sifted weekly. Pupae were transferred to smaller plastic containers (9.2 cm in diameter by 4.7 cm in height, Highland Plastics) with screened lids and sand and held until emergence of flies or parasitoids. Fruit were held in a room maintained at 22 ± 5°C, ambient (40–90%) RH, and a photoperiod of 12:12 (L:D), and recovered pupae were held in an environmental cabinet maintained at 25 ± 2°C, 60 ± 10% RH, and a photoperiod of 12:12 (L:D) h. Numbers of melon fly and *P. fletcheri* that emerged were recorded. Dead pupae were dissected to determine whether parasitization had occurred. To determine individual infestation of fruit, four lots of 250 fruit were collected from four different sites during April 1997. These fruit were held individually in small plastic cups with screened lids to determine infestation and parasitization rates per individual fruit. These results were pooled ($n = 1000$).

***P. fletcheri* Field Cage Studies.** *P. fletcheri* wasps were obtained from a colony maintained for 50 generations in the laboratory at the Pacific Basin Agricultural Research Center (PBARC) facility in Honolulu, HI. Parasitoids were shipped inside melon fly pupae to the PBARC facility in Hilo, HI, and allowed to emerge inside plastic buckets (15 cm in depth by 20 cm in diameter). Pupae were placed inside buckets at densities of 1, 2, or 3 g (30 males and 80 females, 80 males and 230 females, and 160 males and 450 females, respectively). Numbers of parasitoids to emerge were determined from emergence inside quality control buckets to determine the number of wasps (males and females) released into cages during experiments. Two quality control buckets were examined per density per replicate. Buckets had screen lids and insects were provided with honey (Sioux Honey Association, Sioux City, IA) and water. Pupae were held in a room at temperatures of 22 ± 5°C, with a relative humidity of 40–90%, and a photoperiod of 12:12 (L:D) h until eclosion. Parasitoids 4–5 d-old, were used in the 24 h exposure tests with fruit collected from wild ivy gourd plants. Freshly picked fruit, 90–100% ripe, and naturally infested with melon fly and *P. fletcheri*, were randomly assigned to treatment and control cages.

Field cage tests were conducted during 1996 at the University of Hawaii field station at Kainaliu, HI, on 22 January 29 January, 5 February, and 5 March (four replicates). Tests were conducted inside nylon screen field cages (3 m in height by 3 m in diameter) set up under the roof of an open-air shadehouse (Prokopy

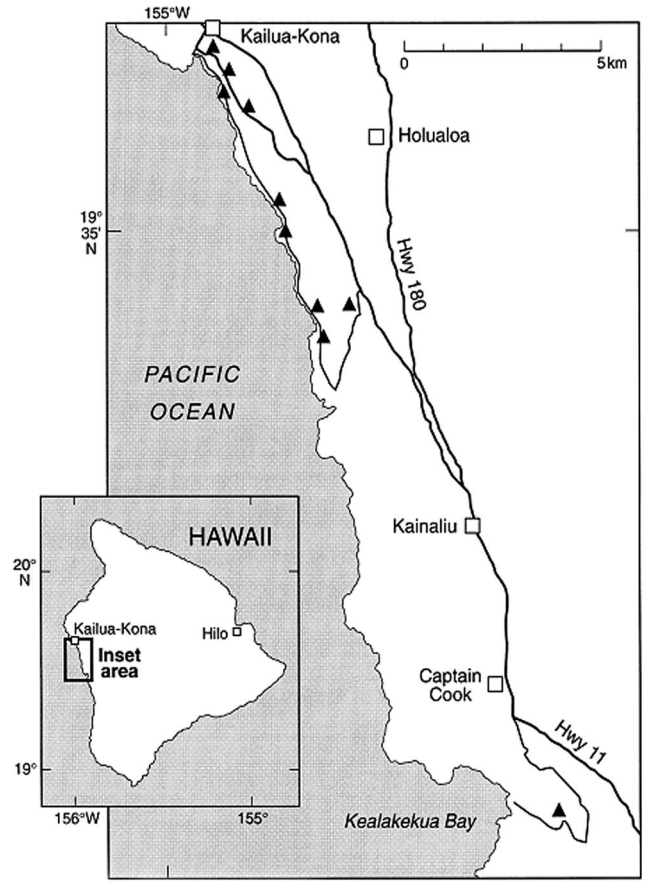

Fig. 1. Map of Kailua-Kona area of Hawaii Island showing study and release sites (triangles).

and Vargas 1996). Four evenly spaced field cages were erected along a north-south transect. A 1.5-m-tall potted guava tree was placed inside each cage to provide a plant canopy for parasitoids. Inside each cage were two fiberglass tray (50 by 32 cm) platforms, mounted on top of a 1-m length of 1.9-cm PVC pipe coated with a 2.5-cm band of Tangle-Trap (Tanglefoot Company, Grand Rapids, MI) and anchored to the ground. Testing began at 0900 hours and ended 24 h later. Fifty ripe fruit were placed on each tray at the beginning of each trial for a total of 100 fruit per cage. Parasitoids were released into three cages at the densities described previously and allowed to oviposit for 24 h. Test fruit were removed from trays, weighed, placed in boxes, and handled as described previously. Pupae were recovered from fruit and held as described previously. Numbers of melon fly and *P. fletcheri* that emerged were recorded, and dead pupae were dissected to determine whether parasitization had occurred.

***P. fletcheri* Open Field Release Studies.** *P. fletcheri* wasps were obtained and handled as described previously. Approximately 1,000 pupae were placed and held inside 1.95-liter paper buckets (Sweetheart Cup Co. Inc., Owings Mills, MD). Percentage of parasitoids to emerge was estimated from three quality control paper buckets held in the laboratory to estimate the number of wasps released into plots during experiments. Buckets with screened lids and insects were provided with honey and water. On the basis of previous surveys, four pairs of release and control plots (four replicates) with ivy gourd plants and fruit, ≈0.5 ha, were selected throughout the town of Kailua-Kona for evaluation of parasite releases. Four separate release tests were conducted during 1996 at Alii Dr. (19° 37.9716 N, 155° 59.344′ W, 35.4-m elevation) on 6 June, Hualalai Rd. (19° 38.240′ N, 155° 59.220′ W, 54.3-m elevation) on 3 July, Middle Keei Dr. (19° 28.077′ N, 155° 54.458′ W, 122.6-m elevation) on 1 August, and Kamehameha III Dr. (19° 35.071′ N, 155° 57.357′ W, 185.9-m elevation) on 10 October. Corresponding control plots were located at Henry St. (19° 38.573′ N, 155° 59.423′ W, 59.5-m elevation), Kuakini Highway (19° 37.799′ N, 155° 59.144′ W, 48-m elevation), Middle Keei Dr. (19° 28.239′ N, 155° 54.383′ W 141.1-m elevation), and Kamehameha III Dr. (19° 34.565′ N, 155° 57.564′ W, 104.2-m elevation), respectively. Mean (±SEM) numbers of parasitoids released from buckets (range 30–33) per location per week were 32,983 ± 3,439, 32,729 ± 5,696, 33,999 ± 2,810, and 37,197 ± 3,337, respectively. There was no

significant difference in the numbers of parasitoids released per site (analysis of variance [ANOVA]: $F = 0.22$; df = 3, 11; $P = 0.8817$) (SAS Institute 1999). Wasps were 6 d of age and were released for four consecutive weeks. Two days after the release, 10 fruit were randomly collected from each of 10 sites within a plot for a total of 100 fruit per plot per sample date. Equal numbers of fruit were collected and compared from release and control plots. Fruit were held and processed as described previously.

Field Cage Studies with *P. fletcheri* and Sterile Melon Flies. Tests were conducted at the University of Hawaii field station at Kainaliu, HI, inside the four cages described previously on 30 October 2001, 10 May 2002, and 12 December 2002 (three replicates). Each cage contained five potted guava trees arranged to provide a single plant canopy (1.25 m in diameter). Wild melon flies were the F_1 generation obtained from P_1 stock recovered from infested fruit from papaya orchards at Kapoho, HI. Parasitoids were from the same colony described previously. Sterile melon flies (1:1 male:female) were obtained from the PBARC insect rearing laboratory in Honolulu. Melon fly pupae were reared from a 400 generation-old laboratory colony and irradiated with a Gammacell 220 Excel irradiator (MDS Norton, Kanata, Canada) at 10 KR.

The three treatments (sterile flies, *P. fletcheri* and sterile flies, and *P. fletcheri*) and a control were randomly assigned to four cages. All experiments began with wild F_1 melon flies (200 males and 200 females) being introduced into each cage. Wild flies were released 2 d after eclosion. Cages with sterile flies contained ≈8,000 irradiated melon fly pupae placed inside a small plastic tray on one of the platforms. Sterile flies were allowed to emerge and roost in the guava tree canopy. Ratio of sterile males to wild females was ≈20:1, at the beginning of the experiment. In treatments with *P. fletcheri*, 200 5-d-old male and female wasps were released into the cages 5 wk after the beginning of the test, when wild flies had matured. All insects were provided with water contained in 3.8-liter plastic buckets with lids fitted with a 45.7-cm strand of 0.9-cm-diameter cotton dental wick and a plastic tray (17.5 by 12.5 by 4 cm) with 300 ml of a 3:1 volumetric mixture of sugar and enzymatic yeast hydrolysate (U.S. Biochemical Corp., Cleveland, OH). Water and food were placed on the platform inside the cage. Honey was also streaked on pieces of lumite screen attached to the ant-resistant platforms.

Five weeks from the start of the test, four zucchini fruit were placed on each of the platforms on top of a 1.25-cm layer of sand. Fruit were weighed and washed before placement on platforms. Larvae from wild melon flies were allowed to develop inside fruit for 12 d. Test fruit were weighed, placed in fiberglass boxes and handled as described previously. Pupae were recovered from fruit and held as described previously. Numbers of emerged melon flies per gram of fruit were calculated.

Statistical Methods. For trap survey data, melon fly captures were summarized monthly (melon flies per trap per day). For fruit survey data, numbers of melon flies and *P. fletcheri* recovered from fruit for all sites were pooled and summarized (melon flies per gram) by month. Numbers of *B. cucurbitae* and *P. fletcheri* recovered from fruit in the cage parasitoid tests were analyzed by Proc GLM (SAS Institute 1999). Numbers of *B. cucurbitae* and *P. fletcheri* recovered from fruit were transformed to $\ln(x + 1)$ to stabilize variances. For open field releases, melon fly and *P. fletcheri* data were analyzed with a repeated measures ANOVA. A split-plot design was used with main plots arranged in a completely randomized design. The main plot treatments were release and the subplot factors were date. A GLIMMIX.SAS macro was used. It allowed for Poisson distributed count data as the response and fits a split-plot, mixed model (Littell et al. 1996). A probability level of 0.05 was used as the significance criterion for all statistical tests (SAS Institute 1999).

Results

Melon Fly and *P. fletcheri* Ecology. During a 1-yr survey of ivy gourd patches in Kailua-Kona from April 1996 to March 1997, highest numbers of male melon flies were captured during late summer with a monthly mean (±SEM, $n = 12$) of 29.33 ± 14.94 flies per trap per day (Fig. 2). Approximately 32.4% of the fruit were infested with a mean (±SEM) emergence of 2.05 ± 0.13 melon flies per fruit; with 5.7% of the fruit containing *P. fletcheri* (mean ±SEM, 0.22 ± 0.04 wasps per fruit). Numbers of flies recovered from fruit ranged from 0.05 to 0.27 flies per gram (Fig. 3). Parasitization of melon fly by *P. fletcheri* ranged from 1 to 14%.

***P. fletcheri* Field Cage Studies.** Mean (±SEM) numbers of melon flies emerging from fruit placed inside a control and three treatment cages (1-, 2-, and 3-g densities of parasitized pupae) were 131.8 ± 19.4, 29.8 ± 8.8, 35.6 ± 8.3, and 6.4 ± 2.9 melon flies per 100 fruit, respectively (Table 1). All treatment densities differed significantly ($F = 6.31$; df = 3, 16; $P = 0.0005$) from the control. Although there was a numerical difference, there was no significant difference ($P > 0.05$) among the treatments. Mean (±SEM) numbers of *P. fletcheri* to emerge from fruit in the control, and the three treatment cages were 5.2 ± 1.8, 48.0 ± 11.0, 59.2 ± 12.4, and 32.4 ± 8.4 *P. fletcheri* per 100 fruit, respectively. All treatments differed significantly ($F = 20.8$; df = 3, 16; $P < 0.0001$) from the control. There was no significant ($P > 0.05$) difference among treatments.

***P. fletcheri* Field Releases.** In field releases, the effects of treatment ($F = 7.40$; df = 1, 8.57; $P = 0.0247$) and week ($F = 6.93$; df = 4, 17.9; $P = 0.0015$) were significant in determining parasitization rate (15.2% for release and 3.3% for control plots) (Table 2); however, the week × treatment interaction was not significant ($F = 0.78$; df = 4, 18.1; $P = 0.5552$). The effects of parasitoid releases ($F = 1.00$; df = 1, 4.08; $P = 0.3735$) and week ($F = 0.43$; df = 4, 17.7; $P = 0.7880$) did not have a significant effect on emergence of flies from fruit. The week × treatment interaction was also not significant ($F = 1.01$; df = 4, 17.6; $P = 0.4284$).

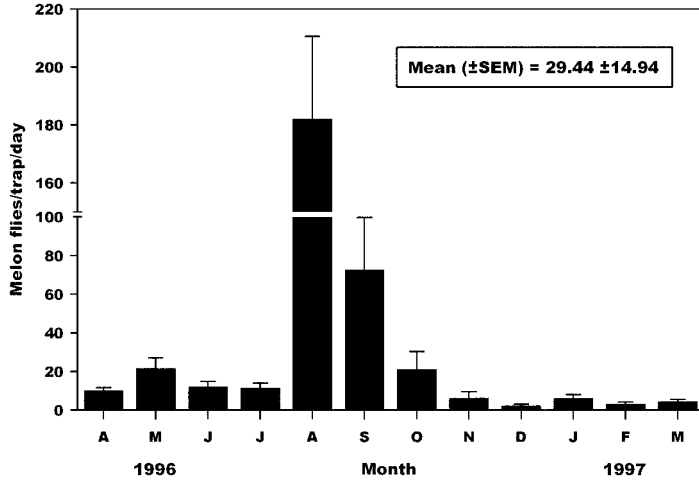

Fig. 2. Captures of male melon flies (mean ± SEM) in cue-lure traps maintained in patches of ivy gourd throughout Kailua-Kona, HI, from April 1996 to March 1997.

Sterile Melon Flies and *P. fletcheri* Releases. In cage tests with sterile melon flies and *P. fletcheri*, treatment had a significant ($F = 4.00$; df = 3, 9; $P = 0.0459$) effect on emergence of flies from fruit. Mean (±SEM) numbers of melon flies emerging per gram of fruit from cages with parasitoids alone, sterile flies alone, and sterile flies and parasitoids together were 0.68 ± 0.34, 0.16 ± 0.08, and 0.10 ± 0.09, respectively, compared with 0.84 ± 0.14 melon flies per gram for a control cage (Table 3).

Discussion

Melon Fly and *P. fletcheri* Ecology. In a previous study of ivy gourd in Kailua-Kona, HI, during 1994 and 1995, 0.5–0.8 adult melon flies were obtained per gram of fruit and only 5–6% of the melon flies were parasitized by *P. fletcheri* (Jackson et al. 2003). In studies of *P. fletcheri* by Nishida (1955), parasitization rates were highest in winter and lowest in summer. Our trap and fruit surveys of ivy gourd patches during 1996 and 1997 in Kailua-Kona indicated highest melon fly captures during late summer, a range of 0.05–0.27 adult melon flies obtained per gram of fruit, 1–14% parasitization by *P. fletcheri*, and lower parasitization rates during summer than in winter. All studies in Hawaii to date (Uchida et al. 1990, Jackson et al. 2003) suggest ivy gourd is an excellent host of melon fly, with *P. fletcheri* being the major parasitoid, albeit in low numbers. Our findings have implications not only for Hawaii but also for the Pacific region where ivy gourd is being spread. For example, in the northern Mariana

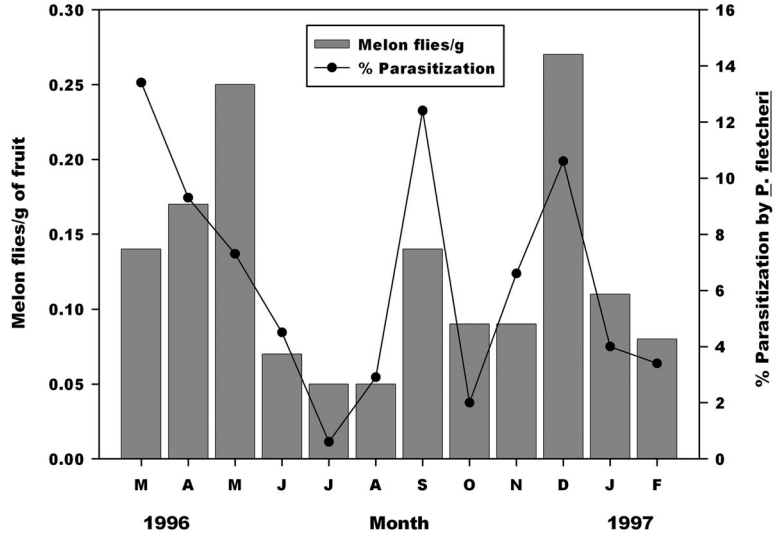

Fig. 3. Population dynamics of melon fly and *P. fletcheri* as determined from fruit samples collected from March 1996 until February 1997 throughout Kailua-Kona, HI.

Table 1. Number of melon flies and parasitoids emerging from ivy gourd fruit placed inside cages with three densities of *P. fletcheri*

Species	Treatment (No. [mean ± SEM] emerging/100 fruit exposed 24 h)			
	P. fletcheri parasitized pupae placed inside cages (g)			
	0	1	2	3
Melon fly	131.8 ± 19.4a	29.8 ± 8.8b	35.6 ± 8.3b	6.4 ± 2.9b
P. fletcheri	5.2 ± 1.8a	48.0 ± 11.0b	59.2 ± 12.4b	32.4 ± 8.4b

Values in the same row followed by the same letter are not significantly different according to Tukey's studentized range (honestly significant difference) test at the $P = 0.05$ level (SAS Institute 1999).

islands of Rota, Tinian, and Saipan where melon fly was eradicated in 1965 (Steiner et al. 1968, Mitchell 1980), it has become reestablished from Guam (Mitchell 1980), and due to an abundance of ivy gourd, has now become a very serious pest of local agriculture (McGregor 2002).

Newell et al. (1952) and Nishida (1955) found that *P. fletcheri* attained high levels of parasitization in wild bitter melon fruit, but it was scarce in cultivated fruit (Nishida 1953), even though wild and cultivated areas were contiguous. Initially, >50% parasitization of melon fly was reported from collections of infested cucurbits (Willard 1920); however, subsequent studies indicated considerably lower parasitization rates, particularly in cultivated areas (Nishida 1955). Nishida (1955) also observed that *P. fletcheri*, like the melon fly, preferred weedy fields, but it was inactive under intense light and high temperatures. In comparing parasitization data obtained in Hawaii and India, it seemed that in both localities the parasitoid is most active during the fall and winter, but the percentage of parasitized larvae was considerably less in India than in Hawaii. Duration of the period in which the parasitoid showed its maximum activity throughout the year was also shorter in India (Nishida 1955). Purcell and Messing (1996) suggested that parasitization was higher in rotting fruit on the ground than in commercially ripe fruit. In the current study, *P. fletcheri* was detected year-round in wild ivy gourd patches. However, unlike with wild bitter melon, parasitization rates of *P. fletcheri* infesting melon fly in ivy gourd were low. Nonetheless, the persistent infestation of ivy gourd by melon fly and low *P. fletcheri* parasitization rates provided an ideal opportunity to test the effectiveness of augmentative parasitoid releases of *P. fletcheri* against melon fly.

***P. fletcheri* Releases.** Several studies have demonstrated the feasibility of parasite augmentation with fruit flies. In Hawaii, release of *Diachasmimorpha tryoni* (Cameron) (at 20,000 per square kilometer per week over a 14-km^2 area) more than tripled Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), parasitization rates (Wong et al. 1991). In Florida, release of 20,000–60,000 *Diachasmimorpha longicaudata* (Ashmead) wasps per week (in 5- and 13-km^2 areas) reduced populations of Caribbean fruit fly, *Anastrepha suspensa* (Loew), by 95% (Sivinski et al. 1996). In Mexico, aerial releases of *D. longicaudata* resulted in increased parasitization rates in mango orchards and a 2.7-fold suppression of *Anastrepha* spp. populations in backyard orchards (Montoya et al. 2000). In the current study with releases of *P. fletcheri* against melon fly, numbers of melon flies emerging from fruit placed inside treatment cages were reduced up to 21-fold, and numbers of parasitoids were increased 11-fold. In open field releases of *P. fletcheri* into ivy gourd patches throughout the Kailua-Kona area, parasitization rates were increased 4.7 times in release plots compared with those in control plots. However, this increase was not high enough to significantly ($P > 0.05$) affect the emergence of flies from fruit. When our results obtained in field cages were compared with those from open field releases, our conclusion is that in patches of ivy gourd, parasitoids had more difficulty finding highly dispersed melon fly larvae in fruit often hidden in vegetation, compared with field cage tests where infested ivy gourd fruit on platforms were more easily located. Comparison of our results from cage and field tests suggest that higher parasitization rates (32.4–48%) are easily obtained in the cage situation where

Table 2. Number of melon flies emerging from fruit and percentage of *P. fletcheri* parasitization based on fruit sampled from control and release plots

Test	Wk	Treatment	Estimate	Upper	Lower
Flies/g	1	C	0.042	0.008	0.212
	1	R	0.036	0.008	0.161
	2	C	0.089	0.020	0.400
	2	R	0.027	0.006	0.120
	3	C	0.050	0.011	0.235
	3	R	0.025	0.005	0.116
	4	C	0.063	0.013	0.316
	4	R	0.033	0.007	0.156
	5	C	0.026	0.005	0.137
	5	R	0.045	0.007	0.271
Parasitization (%)		C	3.3a	1.0	14.9
		R	15.2b	3.2	36.0

C, control site; R, release site. Least squares means and 95% CI. Values in each category followed by the same letter are not significantly different at the 0.0025 level (PROC MIXED, Littell et al. 1996).

Table 3. Mean melon flies recovered from fruit placed inside one of four treatment cages

Treatment	Melon fly/g (mean ± SEM)	
Control	0.84 ± 0.14	A
P. fletcheri	0.68 ± 0.34	AB
Sterile melon flies	0.16 ± 0.08	B
P. fletcheri/sterile melon flies	0.10 ± 0.09	B

Values in the same column followed by the same letter are not significantly different at the $P = 0.05$ level (least significant difference, PROC GLM, SAS Institute 1999).

parasitoids had easy access to larvae but was much more difficult in the weedy field situation (15.2%) where melon fly larvae were highly dispersed throughout the field inside fruit.

Sterile Melon Fly and *P. fletcheri* Releases. Eradication of melon fly by overflooding with sterile males was first demonstrated in the northern Mariana Islands by Steiner et al. (1968). Melon fly was subsequently eradicated from the Okinawa Islands with sterile melon flies at ratios of <10:1 (sterile males:wild females) (Koyama 1996). In the present field cage studies, sterile flies had a significant effect on melon fly infestation of zucchini fruit. Releases of sterile flies at ratios of 20:1 were found to be effective and rapid at reducing melon fly infestation in zucchini. Knipling (1979, 1992) proposed the use of sterile insects and parasitoids for eradication of insect populations. Combinations of sterile insect and parasitoid releases were used to suppress Mediterranean fruit fly populations in Kula, HI (Wong et al. 1992). In Guatemala, reports suggest successful control of Mediterranean fruit fly on coffee, *Coffea arabica* L., farms by augmentative release of *D. longicaudata* and sterile flies (Cancino-Diaz et al. 1996). Our results in field cages confirm the compatability of parasitoid releases followed by sterile fly releases. In the present cage tests with sterile melon flies and *P. fletcheri*, combinations of sterile flies and *P. fletcheri* produced the greatest numerical reduction (9-fold) in melon fly emergence from fruit, although the reduction was not statistically different than sterile flies or parasitoids alone. However, reductions obtained with sterile flies alone or in combination with parasitoids were significantly greater than ($P < 0.05$) the control, whereas those for parasitoids alone were not. These results suggest that the effect of sterile flies on adult reproduction may be greater than parasitoid mortality on larvae for applications in an integrated pest management (IPM) system. Nonetheless, the effects of the sterile melon flies and the parasitoids were on different stages of the insect, the adult and larval stages, respectively, and would seem to be compatible from an IPM perspective, when multiple strategies are desirable.

Melon fly is a severe pest on small melon and vegetable farms throughout Hawaii. In 1999, USDA–ARS funded the Hawaii Fruit Fly Areawide Pest Management program to suppress melon flies below economic thresholds, while reducing the use of organophosphate insecticides on farms (Vargas et al. 2003a). The program includes developing and integrating biologically based pest control technology into a comprehensive management package that will be economically viable, environmentally friendly, and sustainable. Components includes 1) field sanitation; 2) protein bait sprays (Vargas et al. 2001); 3) male annihilation (Vargas et al. 2000); and if needed, 4) augmentative parasitoid releases and 5) sterile insect releases. The present small plot and field cage results provide positive evidence on the use of sterile flies and parasitoids for suppression of melon fly. However, the modest reductions obtained with parasitoids, suggest that parasitoid releases are not the entire solution to melon fly suppression, although in many habitats and from an IPM perspective, they would be useful. In demographic projections by Vargas et al. (2002), *P. fletcheri* was shown to possess an intrinsic rate of increase 25% less than that of melon fly. This suggests that even if *P. fletcheri* could locate most of the melon fly larvae, it would not be able to keep pace with the melon fly, on the basis of a lower reproductive rate. Furthermore, our results showing modest *P. fletcheri* parasitization rates compared with other Hawaiian fruit fly parasitoids such as *Fopius arisanus* (Sonan) (Vargas et al. 2001) suggest that a search for more effective melon fly parasitoids for introduction into Hawaii might be considered. Based on our cage studies, what may supplement the effectiveness of these parasitoids would be the addition of sterile fly releases to an IPM system. Our data suggest that releases of small numbers of sterile flies would have an immediate effect on fruit infestation over a single generation. For example, if the net reproductive rate (2.6-fold increase per generation) of melon fly was reduced by 50% over one generation, there would be a 1.3-fold decrease in the number of females produced per female in the next generation (Vargas et al. 1997). These findings will be further tested in an area-wide demonstration site at Kamuela, HI, where both *P. fletcheri* and sterile melon flies will be released. It remains to be determined whether sterile flies and augmentative parasitoid releases will be cost-effective and sustainable in area-wide IPM systems in Hawaii.

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